Composite Integrally Bladed Turbine

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A ceramic composite integrally bladed turbine disk (blisk) combines two important technology benefits: (1) reduced weight resulting from both a reduced parts count and from use of a lower-density material and (2) improved damping, a derivative of the inherent damping offered by continuous fiber-reinforced ceramic composites. An added benefit is the possibility of reduced operating costs due to enhanced durability (relative to metals) in the intended gaseous oxygen-rich environment. However, the structural response of these single-piece structures to high-vibration environments must be considered. An unshrouded metallic blisk provides little or no damping; without damping there is a degradation of high-cycle fatigue life, and the blisk may become the turbopump's life-limiting component. Use of composites is anticipated to impart needed internal damping to the configuration to address the vibratory stresses encountered because of the unsteady flow loads (random vibration) through the bladed turbine regions. A team of engineers from MSFC and Lewis Research Center was formed to execute a technology development plan to characterize the extent to which composites can damp these vibrations. In addition, unique, gaseous oxygen-rich environments data will be generated that will broaden the application of composites.

This task will produce enabling technology for single-piece, unshrouded composite turbines for gaseous oxygen-rich operation, and supports long-term/high-payoff concepts where composites may be considered as a means to achieve goals of lower engine weight and life-cycle cost. The effort is aimed at providing advance data for two critical design issues: structural dynamics integrity and gaseous oxygen-rich turbine environmental compatibility. Once these areas are baselined in the Simplex turbopump, demonstration of the design in reusable launch vehicle-type operating conditions will be warranted. This particular task is directed to benchmark ceramic-matrix composite design methodologies required to address the most critical fundamental design issues.

The program is divided into two phases. Phase I involves researching and identifying existing relevant data bases in order to establish the current state of knowledge; establishing a material selection criteria test matrix; selecting and obtaining samples of the fiber/matrix composite candidate(s); performing subscale damping, thermal shock, and liquid-oxygen compatibility bench tests; characterizing candidate composite materials for the Simplex pump environment; and generating a Simplex pump turbine region design configuration based on composite material blisk design. Phase II consists of the actual hardware fabrication and testing. These efforts include generating a preliminary test plan, conducting a preliminary design review for a full-scale blisk, fabricating and delivering a full-size composite blisk sample(s) for baseline technology validation tests, and performing hot-fire turbopump testing and pre- and post-inspection of a blisk.

During the early portion of Phase I, key design issues were addressed: selection of the composite material for the blisk, generation of a materials test matrix, and identification of critical design parameters and attachment issues. An extensive government/industry survey was conducted over a period of several weeks in order to identify the current state of knowledge on design and development issues for a ceramic-matrix composite blisk. Participation included members from the Department of Defense and the Department of Energy; associated engineers from the Lewis Research Center, White Sands Test Facility, and MSFC, and industry fabrication and end-item use companies with experience in similar applications. Teleconferences provided data and visibility into industry capabilities and experiences with composites. Subsequent design actions were then initiated in two major areas: attachment between composite disk and metal shaft and the modification of the inertia-welded Simplex disk to shaft design to accommodate the composite disk and shaft configuration.

For the remainder of fiscal year 1995, work was performed on three parallel fronts: structural assessment, design efforts, and materials characterization. Two carbon fiber architectures, quasi-isotropic (0/±60) fabric layup and polar (0/90) fabric layup (to simulate a polar weave), were selected for material characterization panels. These panels will be densified using the isothermal chemical vapor infiltration process.

Key issues which have arisen in finalizing the matrices have been the requirements and approach for both high-cycle and low-cycle fatigue testing, oxygen compatibility test requirements and test article geometries, and friction factor/surface effects testing. These issues have been resolved through several detailed discussions involving government and industry participants. Subscale testing will be performed to support materials characterization and attachment design efforts toward the end goal of placing the composite blisk configuration into the Simplex turbopump in fiscal year 1997.

Composites, with potential for damping due to the makeup and interaction of their substructures, provide unique and alternative nonintrusive damping concepts and can be applied in industry where severe vibration environments are experienced (space and nonspace): rotating industrial machinery, automotive or turbomachine systems, and advanced and current liquid rocket engines. MSFC is continuing, as part of its proactive initiative, to examine mechanisms for improved damping for the upcoming designs that promote use of lightweight, single-piece composites. The composite blisk is one of many such potential applications which, when benchmarked through operational environments, could be extended into other industry uses.

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